Climate crisis: do we need millions of machines sucking CO2 from the air?

From turning CO2 into rock to capturing the breath of office workers, a growing number of companies think the answer is yes

The Canadian firm Carbon Engineering's pilot plant pellet reactor and associated equipment. Photograph: Carbon Engineering

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Does the world need millions of machines sucking carbon dioxide directly out of the air to beat the climate crisis? There is a fast-growing number of companies that believe the answer is yes and that are deploying their first devices into the real world.

From turning CO2 into rock in Iceland, to capturing the breath of office workers, to "putting oil back underground", their aim is to scale up rapidly and some have already sold their CO2 removal services to buyers including Bill Gates, Swiss Re, Shopify and Audi. Prices, however, are sky high – $600 (£440) per tonne and more. Given that humans emit about 36bn tonnes a year, that is problematic. .

Direct air capture (Dac), as the technology is known, is challenging in more ways than just financially. Despite its potent climate heating properties, CO2 makes up just 0.04% of air and so trapping a tonne of the gas means processing a volume of air equivalent to 800 Olympic swimming pools.

“It is not super intuitive,” says Jan Wurzbacher at Climeworks, which just opened the world’s biggest Dac plant in Iceland and recently hosted a conference for the Dac industry. “But that doesn’t mean it is hard. There is no physical reason it can’t be done for $100/tonne in the next 10-20 years.”

The Dac industry is still young and there is a proliferation of technologies and business models, though most use modular machines that should be easier to manufacture and stack.

Gauges, valves and pipes for water, heating and CO2 at the Gebr Meier greenhouse in Hinwil outside Zurich. The heating and the CO2 is sourced from the local waste incinerator, where the CO2 is collected by the Swiss company Climeworks. Photograph: Orjan Ellingvag/Alamy

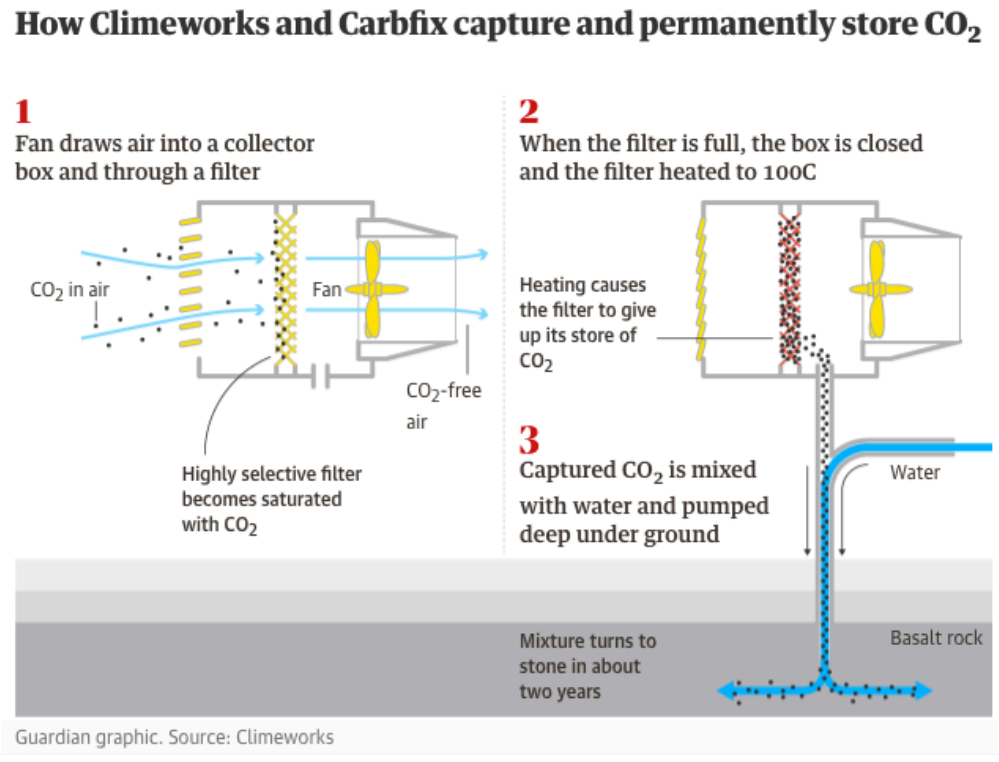
Climeworks’ units use fans to pass air over a solid material that absorbs CO2. When the material is saturated, it is heated to 100C (212F) and releases a stream of pure CO2. Its Orca plant in Iceland uses renewable geothermal energy.

The CO2 is then taken by a partner company, Carbfix, and put underground with water, where it solidifies into rock in two years. About 4,000 tonnes a year will be captured and the company is also working on projects in Oman and Norway.

Canadian firm Carbon Engineering takes a similar approach to CO2 capture but is looking to bury the CO2 in depleted oil and gas reservoirs in the US and the North Sea off Scotland, effectively reversing the flow in existing pipes. “Rather than the transportation of gas in, it’s the transportation of CO2 out,” says Amy Ruddock, the company’s European head.

“Importantly, there is a huge overlap between the skill sets required to do Dac and traditional oil and gas, so it really supports the green transition,” she says. The company aims to bury 1m tonnes a year in the US in 2025, at about $300/tonne. The company also wants to use its technology to provide CO2 as a feedstock for producing low-CO2 jet fuel. “That’s the largest market we’re seeing at the moment,” Ruddock says.

Peter Reinhardt, CEO of Charm Industrial, has an even more striking pitch: “We put oil back underground.” The company takes agricultural and forestry waste that would otherwise rot – emitting CO2 – and heats it to create “bio-oil” that is then pumped back into empty oil reservoirs.



The first injection took place in Oklahoma in January and the equivalent of 1,400 tonnes of CO_2 has been buried this year, at a cost of $600/tonne. “Obviously there is a long way to go – it’s a drop in the bucket compared to the scale of the problem,” Reinhardt says. But if 500,000 machines are deployed, he says, a billion tonnes could be buried at $50/tonne.

CarbonCapture Inc, a US firm, is using “molecular sieves” called zeolites to capture the CO_2. Handily, zeolites are already produced in huge volumes for use in laundry detergents, oil refineries and sewage plants. In the Netherlands, Carbyon hopes using thin-film technology will make its machines faster at separating the CO_2 from the air.

Rendering showing what will be the world’s largest Dac plant, currently being engineered by Carbon Engineering and 1PointFive. Photograph: Carbon Engineering Ltd

Energy use is a big concern if Dac is to be deployed at massive scale and Mission Zero Technologies uses electrochemical processes to release the captured CO_2, which it says means 3-5 times less power is needed than for heat-based processes.

Another firm, Heirloom, does away with fans and allows heat-treated rocks to passively absorb CO_2 over a couple of weeks, before more heating liberates the

gas. “We are trying to turn this Dac problem from a chemical engineering problem into an industrial automation problem,” says Shashank Samala. “Imagine white powder on cookie trays in cafeteria tray racks – it’s pretty simple.”

There are also other business models. Soletair Power’s approach is to turn buildings into CO2-capturing machines. The CO2 in exhaled breath makes offices stuffy and can reduce worker productivity, says CEO Petri Laakso. “Basically people are more stupid indoors and that means thousands of dollars of loss for companies in offices,” he says. “We have a different business logic: we sell fresh indoor air as a service.” The company’s current office unit can capture a kilogram of CO2 every 8 hours.

A lack of commercial CO2 supply recently hit the UK, and AirCapture, based in California, is developing onsite machines that suck CO2 from the air to produce streams for businesses such as drinks companies. Most CO2 today is produced from fossil fuels and has to be trucked to sites.

But can these systems really play a significant part in beating the climate crisis?

Pipework inside a pod, operated by Carbfix, containing technology for storing carbon dioxide underground, in Hellisheidi, Iceland. Photograph: Bloomberg/Getty Images

The biggest and most urgent task in beating the climate emergency is to slash the burning of fossil fuels to as close to zero as possible. The problem is that some sectors are very hard to decarbonise, such as farming, aviation and certain industrial processes, and these emissions have to be mopped up to stop global heating.

It is also likely, given that CO2 emissions are actually still rising, that the world will overshoot the carbon budget for the internationally agreed 1.5C target. This also means CO2 is going to have to be pulled from the air. The Intergovernmental Panel on Climate Change concluded in 2018 that billions of tonnes of CO2 a year may need to be captured and buried after 2050.

"Unless affordable and environmentally and socially acceptable CO2 removal becomes feasible and available at scale well before 2050, 1.5C-consistent pathways will be difficult to realise, especially in overshoot scenarios," the IPCC said. "Roughly, we need to take care of 10 billion tonnes of CO2 each year in mid-century," says Wurzbacher.

Dac, however, is not the only option. Growing crops, burning them to produce power, and burying the emissions also removes CO2, but scientists worry about the huge land and water requirements. Growing trees – the original CO2 removal machines – is also an option, but also requires a lot of land, takes time and the forests then have to be protected for decades or the CO2 goes up in smoke.

Prof Thomas Crowther, an ecologist at ETH Zurich and prominent backer of reforestation, says: "We cannot simply plant a blanket of trees across the planet and hope to save the world – nature isn't going to do this alone. We are undoubtedly going to need thousands of solutions." He says technology for drawing down CO2 has immense potential.

Christoph Gebald at Climeworks is bullish about his company's technology: "We are very confident we can achieve million-tonne [per year] capacity in the second half of this decade, and billion-tonne capacity by 2050."

Businesses are increasingly buying offsets to claim carbon neutrality, often via schemes that claim to protect forests, plant trees or install renewable energy. But many offset schemes are criticised as smoke and mirrors. Gebald argues

that, by contrast, Dac with underground burial offers immediate, permanent and easily measurable CO2 disposal.

Right now, direct air capture is like trying to bail out the Titanic using an eyedropper

Robert Rohde, a climate scientist at Berkeley Earth

Will the financials add up? For all these companies, scaling up to crush the cost of their technologies is critical. Hans De Neve, founder of Carbyon, says solar panels were originally extremely expensive but have plummeted in price, falling by 80% in the last decade alone: "I see no fundamental reason why this can't happen for the Dac industry."

Gebald says Dac will need a subsidy phase. "Solar PV in the 2000s was receiving subsidies well north of $500 per tonne of CO2, and with the support of billions of dollars annually over 10 years, this really helped the industry to scale and drive down costs." Ruddock highlights the cost of unchecked global heating: "The benchmark I would throw out there is what is the cost of going above 1.5C or 2C?"

The other critical factor for large-scale Dac is the creation of a market for CO2 disposal. Jet fuel and clean office air might raise some funds in the near term, but not enough to get to removing billions of tonnes of CO2 a year.

"If there's no price on CO2, it's going to be extremely difficult to establish these technologies," says Prof Reto Knutti, a climate scientist at ETH Zurich. "So I think that governments have to say, yes, there is a price for CO2, and then the private sector can come up with fancy innovative solutions." Negotiations over rules for an international CO2 market will be one of the main issues at the Cop26 summit in November, and the backers of Dac will be hoping for success.

Early adopters of Dac, like Microsoft, are already pushing funding into the sector, and both Elon Musk and the UK government have launched technology competitions worth $100m and £100m respectively. There are also some early offset customers, such as insurance giant Swiss Re, which has signed a 10-year deal with Climeworks, and Shopify, both attracted by the certainty of removal.

Jens Burchardt of Boston Consulting Group, another customer, says: "We think it's something that the world undoubtedly needs to get to net zero and we are

one of not-so-many companies in the world who can afford to give this a push at a time when its economics are not yet where they need to be."

Climate campaigners, such as Greenpeace, have argued that Dac could be a dangerous distraction. "We simply can't wait until tech like Dac is finally affordable or widely available if we want to avoid catastrophic climate change," says Charlie Kronick, senior climate adviser at Greenpeace UK. "If overhyping Dac encourages delay and dithering on the necessary action to cut emissions then it will make the situation worse, not better."

Prof Michael Mann, a climate scientist at Penn State University and author of The New Climate War, says: "Of all of the geoengineering schemes, Dac seems the safest and most efficacious. It could, along with natural reforestation, be an important component of broader efforts to draw down carbon from the atmosphere, a strategy that arguably belongs in any comprehensive climate abatement program. But since we're only talking about capturing 10%, at most, of current carbon emissions, this obviously cannot be a primary strategy for cutting emissions."

"Dac would be an amazing weapon in the fight against climate change," says Robert Rohde, a climate scientist at Berkeley Earth. "However, it remains very small-scale and high cost. Current global capacity for Dac is about 12,000 tonnes of CO2 per year. Each year, human activities release 40bn tonnes. So, right now, Dac is like trying to bail out the Titanic using an eyedropper."

"The industry needs to find a way to rapidly grow many thousands of times larger, and cut costs by about 80%, if they are going to have a real hope of making a tangible impact in the fight against global warming," says Rohde. "It will be great if they can make it work, but I am not optimistic, and most of the world's attention should be focused on reducing emissions because we don't have time to wait."

Scaling up rapidly will require huge investment, but Adrian Corless, CEO at CarbonCapture, points out that many trillions of dollars have been invested in oil and gas infrastructure, which is the source of much of the climate crisis. "I don't think it should scare or surprise anyone that to solve the climate problem it will need an industry on the scale of the oil and gas industry," he says.